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Evaluation of Asbestos Levels in Two Schools Before and After Asbestos Removal

PEI Associates, Inc., Cincinnati, OH

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16. ABSTRACT

This report presents a statistical evaluation of airborne asbestos data collected at two schools before and after removal of asbestos-containing material (ACM). Although the monitoring data are not totally consistent with new Asbestos Hazard Emergency Response Act (AHERA) requirements and recent EPA guidelines, this study evaluates these historical data by standard statistical methods to determine if abated work areas meet proposed clearance criteria. The objectives of this statistical analysis were to compare 1) airborne asbestos levels indoors after removal with levels outdoors, 2) airborne asbestos levels before and after removal of asbestos, and 3) static sampling and aggressive sampling of airborne asbestos. The results of this evaluation indicated the following:

- The effect of asbestos removal on indoor air quality is unpredictable,
- The variability in fiber concentrations among different sampling sites within the same building indicates the need to treat different sites as separate areas for the purpose of clearance, and
- Aggressive sampling is appropriate for clearance testing because it captures more entrainable asbestos structures. Aggressive sampling lowers the chance of declaring a worksite clean when entrainable asbestos is still present.

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EVALUATION OF ASBESTOS LEVELS IN TWO SCHOOLS BEFORE AND AFTER ASBESTOS REMOVAL

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Enviromental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing of research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This report provides information on the nature and controllability of releases of toxic substances to air from product uses, specifically asbestos-containing materials used as fireproofing in building construction. It also provides an evaluation of data collected on airborne asbestos concentrations at two schools, before and after removal of asbestos-containing material (ACM). These historical data are evaluated by standard statistical methods to determine if abated work areas meet the clearance criteria of the Asbestos Hazard Emergency Response Act (AHERA).

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Risk Reduction Engineering Laboratory

ABSTRACT

This report presents a statistical evaluation of airborne asbestos data collected at two schools before and after removal of asbestos-containing material (ACM). Although the monitoring data are not totally consistent with new Asbestos Hazard Emergency Response Act (AHERA) requirements and recent EPA guidelines, this study evaluates these historical data by standard statistical methods to determine if abated work areas meet clearance criteria.

The objectives of this statistical analysis were to compare 1) airborne asbestos levels indoors after removal with levels outdoors, 2) airborne asbestos levels before and after removal of asbestos, and 3) static sampling and aggressive sampling of airborne asbestos.

The results of this evaluation indicated the following:

- The effect of asbestos removal on indoor air quality is unpredictable.
- The variability in fiber concentrations among different sampling sites within the same building indicates the need to treat different sites as separate areas for the purpose of clearance.
- Aggressive sampling is appropriate for clearance testing because it captures more entrainable asbestos structures. Aggressive sampling lowers the chance of declaring a worksite clean when entrainable asbestos is still present.

This report was submitted in fulfillment of Contract No. 68-03-4006 by PEI Associates, Inc., under the sponsorship of the U.S. Environmental Protection Agency. Price Associates, Inc., assisted with the statistical analysis under subcontract to PEI.

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INTRODUCTION

BACKGROUND

The U.S. Environmental Protection Agency (EPA) has undertaken a variety of technical assistance and regulatory activities designed to control asbestos-containing materials in buildings and to minimize inhalation of asbestos fibers. In 1979, the EPA began publishing state-of-the-art guidance to help school administrators and building owners identify and control asbestos hazards in buildings. An important objective of these guidance documents has been to address the question of how to determine when an asbestos-abatement worksite has been successfully cleaned and is acceptable for reoccupancy.

The EPA's second asbestos guidance document, "Guidance for Controlling Friable Asbestos-Containing Materials in Buildings" (Blue Book), describes for the first time a two-part process for determining when an abatement project is complete and the contractor can be released.(1) The two steps are 1) a visual test to determine if the asbestos-containing material (ACM) has been properly abated and the worksite is free of debris and dust, and 2) an air test to determine if residual asbestos fibers generated during removal have been reduced below a predetermined level. The recommended method of sampling and analysis of air samples presented in the 1983 EPA guidance document was the NIOSH method based on phase-contrast microscopy (PCM). The sampling and analysis specifications suggested for air monitoring after project completion included no mention of aggressive sampling and recommended the PCM detection limit as the criterion level for clearance. The limitations of PCM analysis and static sampling techniques for post-abatement clearance testing are now well known and have led to the use of more sophisticated and accurate methods of asbestos identification.

The principal EPA asbestos guidance document, "Guidance for Controlling Asbestos-Containing Materials in Buildings" (Purple Book), was expanded and updated in June 1985.(2) Later in 1985, EPA published a companion guidance document on air monitoring after an abatement action, which discusses the subject in more detail.(3) These documents recommended and presented supportive arguments for the use of aggressive sampling and transmission electron microscopic (TEM) analysis of air samples. In addition, these most recent guidelines contain a recommended protocol for aggressive sampling, a sampling strategy for post-abatement clearance monitoring, and a statistical method for evaluating the TEM results and the adequacy of the contractor's cleanup.

Sampling, analytical, and statistical protocols for clearance testing of an abatement site have undergone yet further revisions as a result of the Asbestos Hazard Emergency Response Act of 1986. The final rule (40 CFR Part

763, Subpart E), which was published October 30, 1987, specifies a detailed aggressive sampling protocol that incorporates the use of a leaf blower and fans, the collection and TEM analysis of a representative and statistically defensible number of air samples from inside and outside the work area, a statistical method (Z-test) for evaluating the TEM results, and numerous mandatory quality control and quality assurance procedures.(4)

This report presents a comparison of historical TEM air monitoring data collected in two schools (under static and aggressive conditions) before and after asbestos removal. To the extent that the data allow, this study attempts to evaluate these data by applying standard statistical methods designed to determine whether the inside airborne asbestos concentrations are significantly higher than the outside asbestos concentrations.

OBJECTIVES

The objectives of this evaluation were:

- To compare airborne asbestos levels after removal with outdoor levels.
- To compare airborne asbestos levels before and after removal.
- To compare two methods of sampling airborne asbestos: static sampling and aggressive sampling.

RESULTS AND CONCLUSIONS

RESULTS

The main results are summarized by school as follows:

School 1

- Airborne asbestos levels prior to removal were not significantly different from outdoor levels. Measured levels increased after removal and were significantly higher than outdoor levels. Four of the six sites failed the Z-test under aggressive sampling. There were significant differences in post-removal levels among sites.

- Aggressive sampling tended to produce higher estimates of airborne asbestos levels at the lower airborne asbestos concentrations before removal than did static samples. This trend was most apparent at the lowest airborne asbestos concentrations and least apparent at the higher concentrations measured after removal.

School 2

- Airborne asbestos levels measured by aggressive sampling were significantly higher than outdoor levels prior to removal. Differences among indoor sites were also significant. Measured levels declined after removal, and three of the four sites passed the Z-test under aggressive sampling.

- Estimates of airborne asbestos levels tend to be higher when aggressive sampling is used rather than static sampling.

CONCLUSIONS

The preceding results lead to the following conclusions:

1) At the schools surveyed, the effect of asbestos removal was unpredictable. Measured airborne asbestos levels indicated reductions after removal in some cases and increases in others.

2) The variability among different sites within the same building, even when the abatement operation is carried out in accordance with presumably uniform specifications, argues for the need to treat different sites as separate areas for the purpose of clearance.

3) Aggressive sampling is appropriate for clearance testing. It tends to capture more asbestos (i.e., measurements by aggressive sampling generally produce larger values than do measurements by static sampling), which lowers the chance of declaring a worksite clean when entrainable asbestos is still present.

RECOMMENDATIONS

Based on the findings of this study, the following recommendations are presented:

- An immediate research objective should be to identify abatement projects in which work acceptance was achieved (per the current EPA clearance criteria) and to describe the final cleaning methods and engineering control strategies used to achieve acceptance.

- The long-term effectiveness of abatement by currently recommended methods should be investigated further. Monitoring of previously abated building areas (including those that were cleared only by PCM methods) by aggressive sampling and TEM methods could help to identify trends in indoor asbestos fiber concentrations over time.

- Future asbestos abatement research studies should focus on AHERA-Rule requirements and incorporate the sampling, analytical, and statistical protocol(s) described therein.

STUDY DESIGN, EXPERIMENTAL METHODS, AND SITE DESCRIPTIONS

During the summer of 1985, air samples were collected on 0.8-μm pore size, 37-mm mixed diameter cellulose ester filters at two schools before removal of the asbestos-containing material (ACM) and after its removal. During each sampling period, samples were first taken without any deliberate attempt to disturb the air (static sampling). A second set of samples was then taken after leaf blowers and fans had been used to resuspend any settled asbestos fibers (aggressive sampling).

Each abatement work area at both schools had an aggressive clearance concentration of less than 0.01 fiber/cm^3 of air before the work area was considered acceptable and before subsequent TEM analyses were performed.

Six sites (rooms) were sampled at School 1, and four sites were sampled at School 2. Three air samples, each consisting of approximately 1450 liters, were collected on 37-mm (0.8-μm pore size) cellulose ester filters at each site. The flow rate was approximately 3 liters per minute. Outdoor samples were collected on the roof of each school--16 at School 1 (6 before removal and 10 after removal) and 10 at School 2 (4 before removal and 6 after removal). Field blanks (filters that are subject to the same handling as standard samples, but through which no air is drawn) were used at both schools (13 at School 1 and 11 at School 2) to check for sources of asbestos contamination other than the air being sampled.

The samples were prepared in accordance with the NIOSH 7402 technique, which is a direct-preparation technique for cellulose ester membrane filters.(5) Samples were analyzed by TEM in accordance with the procedures in Yamate et al.(6) The results are expressed in asbestos structures per cubic centimeter (s/cm^3) for air samples and asbestos structures per square millimeter (s/mm^2) for blanks. When more than one analysis was done on a single filter, the average of the multiple readings was used in the statistical analysis. Results are not available for two samples from School 1, and one sample from School 2 was not analyzed because there was no filter in the cassette when it reached the laboratory. Statistical analyses are based on 99 TEM results from School 1 and 68 from School 2.

PROJECT SITE DESCRIPTIONS

School 1

School 1 contained asbestos fireproofing insulation spray-applied to steel beams, deck, and columns. The range of asbestos content for this

moderately friable material was 30 to 60 percent chrysotile asbestos. This study was coordinated with the second phase of a school asbestos-removal project conducted during the summer of 1985. An analysis of air monitoring data collected during the preceding phase of abatement (summer of 1984) was presented in an earlier EPA report, in which two analytical methods and two sampling schemes were preliminarily evaluated.(7) The study described in this report was a followup to the original study. It was designed to verify (or refute) the conclusions of the initial study and to integrate an improved sampling strategy, a different analytical technique, and new statistical methods for comparing the air monitoring data. The site selection criteria, abatement plan, and sequence of abatement activities are described in detail in the previous EPA report.

School 2

The abatement project at School 2 specified the removal of spray-applied acoustical plaster from the ceilings of classrooms. Analysis of 12 representative bulk samples from the six rooms where air sampling was conducted indicated that the chrysotile asbestos content of the bulk samples was approximately 10 percent. The moderately friable acoustical plaster throughout the building was in generally good condition and had not been previously encapsulated. Reports from Agency representatives who visited the site periodically and observed the abatement process indicate that the procedures used for preparation, removal, and decontamination of work areas were consistent with those described in the EPA guidance documents in effect and available at the time when abatement occurred (i.e., Blue Book, March 1983). The final air samples for this site were collected after the ceilings in the designated classrooms had been resprayed with a nonasbestos replacement acoustical plaster.

STATISTICAL ANALYSIS

METHODS

Asbestos concentrations on the blank filters were examined first to ensure that a contamination problem did not exist before proceeding with the analysis of the field samples.

Samples with an asbestos count of 0 were assigned an estimated airborne asbestos concentration of 0 structures/cm^3. A concentration of 0 was used in all subsequent calculations and analyses with the exception of the Z-test (see below). Some researchers set the airborne asbestos concentration to the analytical sensitivity when the structure count is 0. (The analytical sensitivity, also referred to as the detection limit, is the estimated airborne asbestos concentration calculated when a single fiber is counted in a sample.) In this research study, which involved statistical analysis of multiple samples, it is preferable to use the estimate of 0 rather than substituting the analytical sensitivity because the latter approach introduces a positive bias that may obscure trends of interest.

With the exception of the Z-test (see below) when more than one TEM analysis was performed on a sample, the average of the estimated airborne asbestos concentrations was used to represent that sample.

Statistical analyses were designed to address each of the three objectives listed in Section 1. Summary statistics (mean and standard deviation) were generated for each sampling period, sampling method, and site.

Comparison of Airborne Asbestos Levels After Removal With Outdoor Levels

The Kruskal-Wallis one-way analysis of variance and the Z-test were used to test for differences between indoor and outdoor sites after asbestos removal. The Kruskal-Wallis analysis is a nonparametric test that uses ranks rather than actual data values. Although it is not as powerful as the standard analysis of variance, it does not require assumptions about the distribution of the data.

The Z-test is a standard comparison of means for data that are normally distributed. Because it is based on a log transformation of the data, the particular form of the Z-test required under the AHERA EPA Asbestos-Containing Materials in Schools, Final Rule and Notice, specifies that 0 concentrations are to be replaced by the analytical sensitivity before calculating the Z statistic. As noted earlier, this is the only situation in which the analytical sensitivity was used in place of 0. Also, only the primary TEM

analysis was used in the case where multiple TEM analyses were performed on a single sample. The studies were conducted before the AHERA clearance criteria were developed, and they do not meet all the sampling and analysis requirements. In particular, fewer samples were taken per site (three instead of five) and the analytical sensitivity is higher (0.007 instead of $\leq$0.005 s/cm^3). This means that the Z-test required under AHERA is less likely to detect differences between inside and outside concentrations in studies reported herein compared with studies in which the requirements are met. Nevertheless, the Z-test was applied to each site to gauge the consistency of its results with the results of the Kruskal-Wallis Analysis.

Comparison of Airborne Asbestos Levels Before and After Removal

The average airborne asbestos concentration at each site before removal was subtracted from the average concentration after removal to give a measure of the effect of removal. A t-test was used to test whether this measure, which is approximately normally distributed, is significantly different from zero.

Comparison of Static and Aggressive Sampling

For each site and sampling period, the average airborne asbestos concentration obtained by aggressive sampling was plotted against the corresponding concentration obtained by static sampling, and a correlation coefficient was calculated.

RESULTS AND DISCUSSION

SCHOOL 1

No asbestos fibers were found on any of the 13 blank filters, which indicates that contamination from sources other than the air being sampled is not an important factor. Table 1 presents the mean airborne asbestos level at each site for each sampling period and method. Arithmetic, rather than geometric, means are reported because of the large number of zero measurements.

Comparison of Airborne Asbestos Levels After Removal With Outdoor Levels

Average airborne asbestos levels measured after removal are higher than outdoor levels (Table 1). The Kruskal-Wallis test indicates significant differences among sites for both static ($p<0.001$) and aggressive samples ($p<0.002$). Since the lowest airborne asbestos level was measured outdoors, the significant result implies that the outdoor level is significantly lower than at least some of the indoor levels. Significant differences also existed among the indoor sites ($p<0.02$ for both static and aggressive samples), which indicates that levels after removal can differ from room to room in the same school.

Table 2 presents the results of the Z-test. Five of the six sites failed the test under static sampling, and four failed under aggressive sampling.

Past experiences with final clearance criteria suggest that sufficient air exchange in abatement areas following final cleaning (via negative air systems) is the largest factor in passing the test. Also, meticulous, repetitive wet cleaning and HEPA vacuuming of all surfaces are necessary to remove reentrainable asbestos fibers.

Comparison of Airborne Asbestos Levels Before and After Removal

Average airborne asbestos levels at each site before and after removal are presented graphically in Figure 1, which illustrates both static and aggressive sampling results. Measured levels were higher after removal at all sites, although the difference was not statistically significant ($t=2.01$, $p=0.1$, for static samples; $t=1.17$, $p=0.3$, for aggressive samples) because of the large amount of variability in the magnitude of the difference from site to site. The Kruskal-Wallis test detected no significant differences between indoor and outdoor sites prior to removal ($p=0.99$ for static samples, $p=0.81$ for aggressive samples), but detected significant differences between indoor

TABLE 1. AIR MONITORING RESULTS FOR SCHOOL 1

	Average Airborne Asbestos Concentration, structures/cm³							
	Static sampling				Aggressive sampling			
	Pre-abatement		Post-abatement		Pre-abatement		Post-abatement	
Site	Mean*	STD†	Mean*	STD†	Mean*	STD†	Mean*	STD†
Outdoor	0.002	0.003	0.002	0.003	-	-	-	-
1	0.000	0.000	0.013	0.009	0.001	0.002	0.008	0.013
2	0.000	0.000	0.650	0.187	0.000	0.000	0.060	0.019
3	0.000	0.000	0.032	0.031	0.000	0.000	0.069	0.031
4	0.002	0.003	0.034	0.052	0.002	0.004	0.003	0.006
5	0.000	0.000	0.141	0.074	0.004	0.007	0.052	0.011
6	0.000	0.000	0.483	0.208	0.005	0.004	1.323	0.298

* Arithmetic mean.

† Standard deviation.

TABLE 2: RESULTS OF Z-TEST COMPARISON OF INDOOR AND OUTDOOR AIRBORNE ASBESTOS LEVELS AT SCHOOL 1 AFTER ASBESTOS REMOVAL

Sampling mode	Site	Z-Statistic	Result*
Static Sampling	1	1.16	Pass
	2	8.71	Fail
	3	2.60	Fail
	4	2.12	Fail
	5	5.68	Fail
	6	8.05	Fail
Aggressive sampling	1	0.91	Pass
	2	4.19	Fail
	3	4.37	Fail
	4	0.48	Pass
	5	3.94	Fail
	6	10.08	Fail

* The Z-test is passed when the Z-statistic is $\leq$1.65.

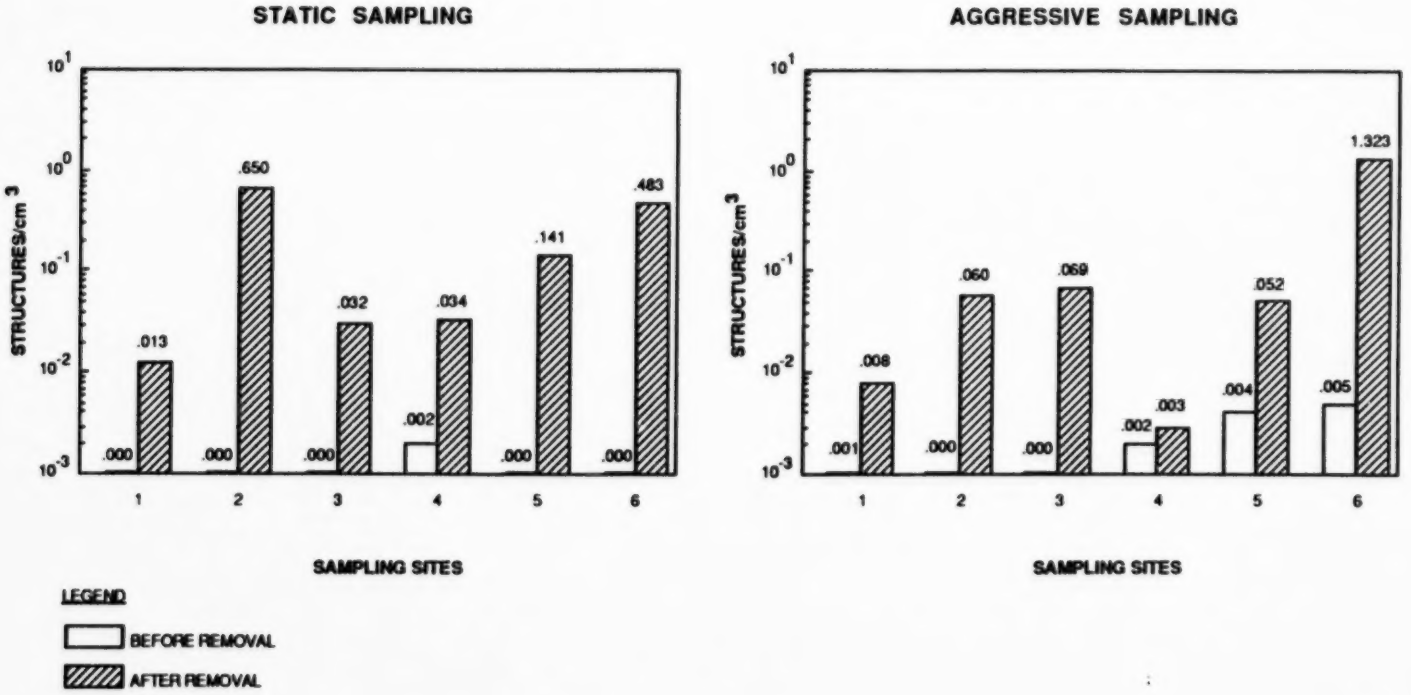

Figure 1. Average TEM airborne asbestos levels measured by static and aggressive sampling at school 1 before and after removal at each site. Sites are identified by number.

and outdoor sites after removal. This indicates that the situation before removal differed from that after removal. Final air quality following asbestos removal appears to be related directly to the adequacy of the final cleaning and to the degree of air exchange occurring in the work area as a result of engineering control systems (e.g., negative air).

Comparison of Static and Aggressive Sampling

In Figure 2, measurements from aggressive samples are plotted against the corresponding measurements from static samples. Measurements taken after removal are denoted by "A"; those before removal, by "B." Points on the vertical axis show that aggressive sampling tends to give higher readings when low readings are obtained by static sampling, but at higher airborne asbestos concentrations, no obvious tendency exists for aggressive samples to give higher estimates. This is to be expected if asbestos fibers are already suspended because of activity (e.g., cleaning) prior to static sampling or if insufficient air exchange (via the negative-air system) has occurred because of the short period between abatement completion and static sampling. The correlation coefficient between aggressive and static measurements is 0.57, which is almost significantly different from zero ($p=0.054$) at the 5 percent level.

SCHOOL 2

No asbestos fibers were found on any of the 11 blank filters, which indicates that contamination from sources other than the air being sampled is not an important factor. Table 3 presents the mean airborne asbestos level at each site for each sampling period and method. Arithmetic, rather than geometric, means are reported because of the large number of zero measurements.

Comparison of Airborne Asbestos Levels After Removal With Outdoor Levels

Average airborne asbestos levels after removal were low (Table 3). No asbestos fibers were detected outdoors. The Kruskal-Wallis test detected no significant differences between indoor and outdoor sites for both static ($p=0.46$) and aggressive samples ($p=0.44$).

Table 4 presents the results of the Z-test. None of the four sites failed the test under static sampling; one site failed the test under aggressive sampling.

Comparison of Airborne Asbestos Levels Before and After Removal

Average airborne asbestos levels at each site before and after removal are plotted in Figure 3, which illustrates both static and aggressive sampling results. Measured levels were lower after removal at all sites except site 4 under static sampling conditions. The reduction was not statistically significant ($t=-1.5$, $p=0.23$, for static samples; $t=1.4$, $p=0.26$, for aggressive samples). The Kruskal-Wallis test detected no significant differences between indoor and outdoor sites prior to removal for static samples ($p=0.25$),

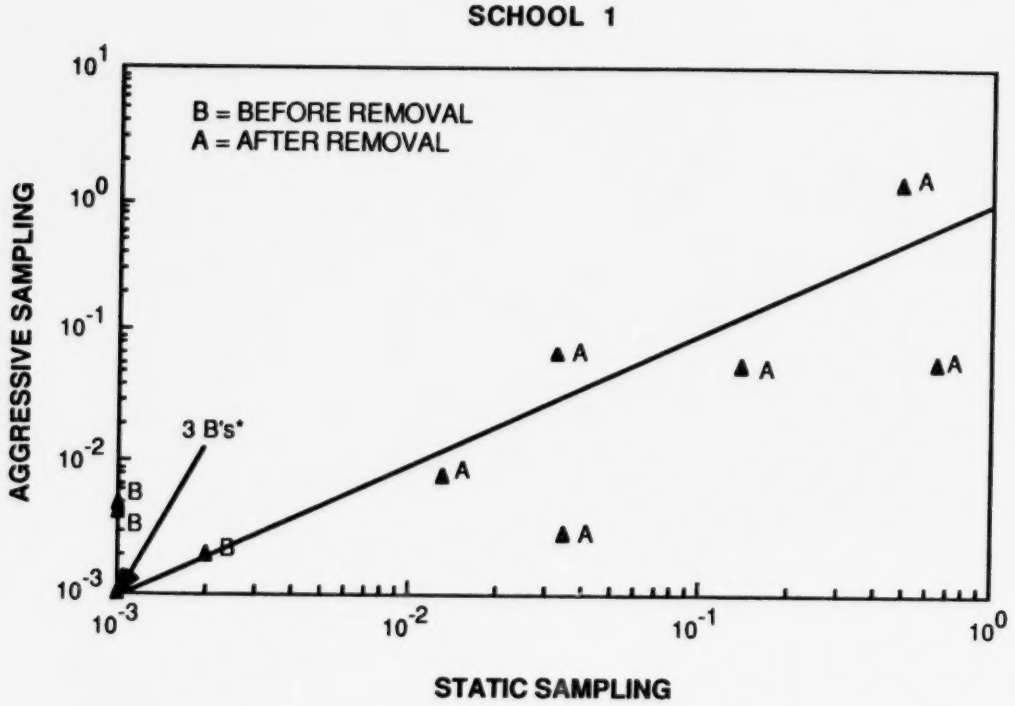

Figure 2. The relationship between average airborne asbestos levels measured by static sampling and by aggressive sampling at school 1.

TABLE 3. AIR MONITORING RESULTS FOR SCHOOL 2

	Airborne Asbestos Concentration, structures/cm³							
	Static Sampling				Aggressive Sampling			
	Pre-abatement		Post-abatement		Pre-abatement		Post-abatement	
Site	Mean*	STD†	Mean*	STD†	Mean*	STD†	Mean*	STD†
Outdoor	0.000	0.000	0.000	0.000	-	-	-	-
1	0.009	0.010	0.000	0.000	0.110	0.046	0.007	0.012
2	0.020	0.035	0.013	0.015	0.016	0.021	0.002	0.004
3	0.002	0.004	0.000	0.000	0.019	0.019	0.002	0.004
4	0.012	0.007	0.015	0.021	0.513	0.373	0.053	0.029

* Arithmetic mean.

† Standard deviation.

TABLE 4: COMPARISON OF INDOOR AND OUTDOOR AIRBORNE ASBESTOS LEVELS USING THE Z-TEST AT SCHOOL 2 AFTER ASBESTOS REMOVAL

Sampling mode	Site	Z-Statistic	Result*
Static sampling	1	-0.31	Pass
	2	0.83	Pass
	3	-0.15	Pass
	4	0.90	Pass
Aggressive sampling	Site	Z-Statistic	Result*
	1	0.35	Pass
	2	-0.32	Pass
	3	-0.32	Pass
	4	3.26	Fail

* The Z-test is passed when the Z-statistic is ≤ 1.65.

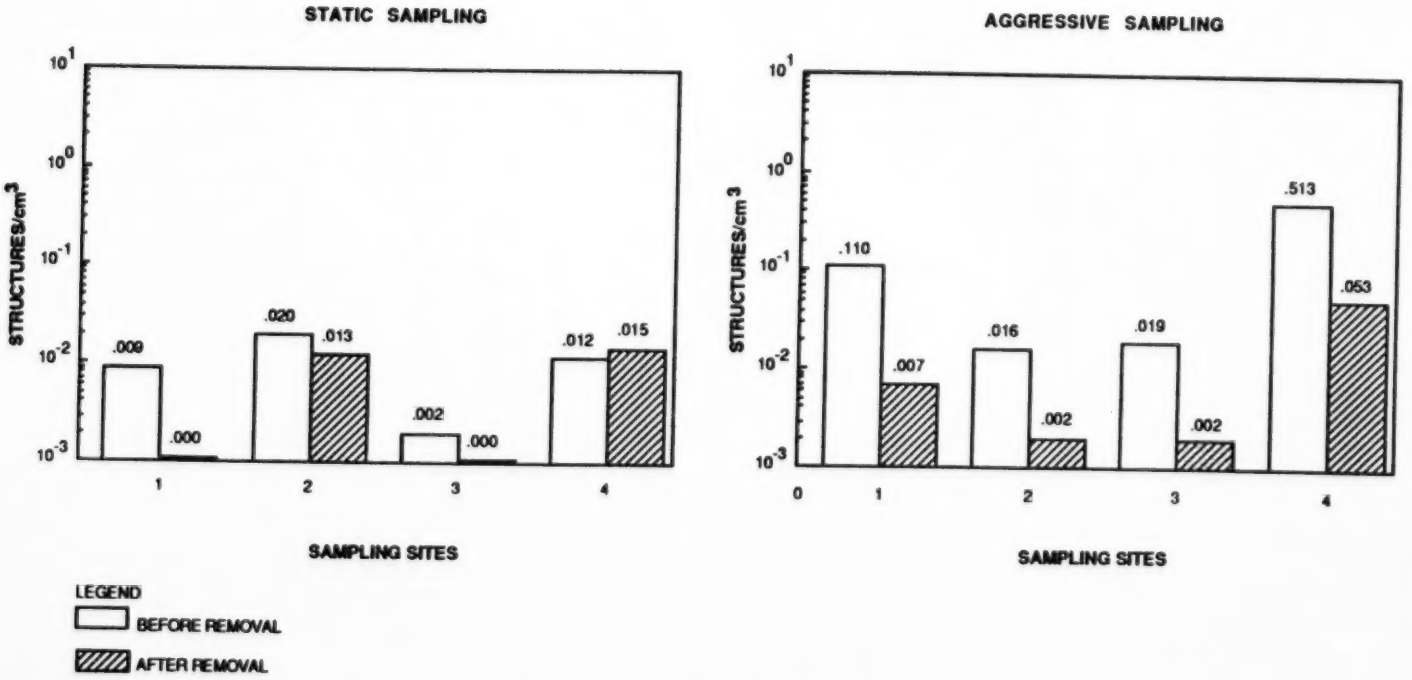

Figure 3. Average TEM airborne asbestos levels measured by static and aggressive sampling at school 2 before and after removal at each site. Sites are identified by number.

but it did detect a significant difference for aggressive samples ($p=0.01$). After removal, no significant differences between indoor and outdoor sites were detected for either static or aggressive sampling. This result indicates that levels measured by aggressive sampling prior to removal are lower than levels measured by aggressive sampling after removal.

Significant differences (Kruskal-Wallis test, $p<0.03$) also existed among the indoor sites measured by aggressive sampling prior to removal, indicating that levels can differ significantly from room to room in the same school.

Comparison of Static and Aggressive Sampling

In Figure 4, measurements taken during aggressive sampling are plotted against the corresponding measurements taken during static sampling. Measurements taken after removal are denoted by "A"; those taken before removal, by "B." The aggressive samples are higher than the static samples in six of the eight cases. The correlation coefficient between aggressive and static measurements is 0.21, which is not significantly different from zero ($p=0.62$).

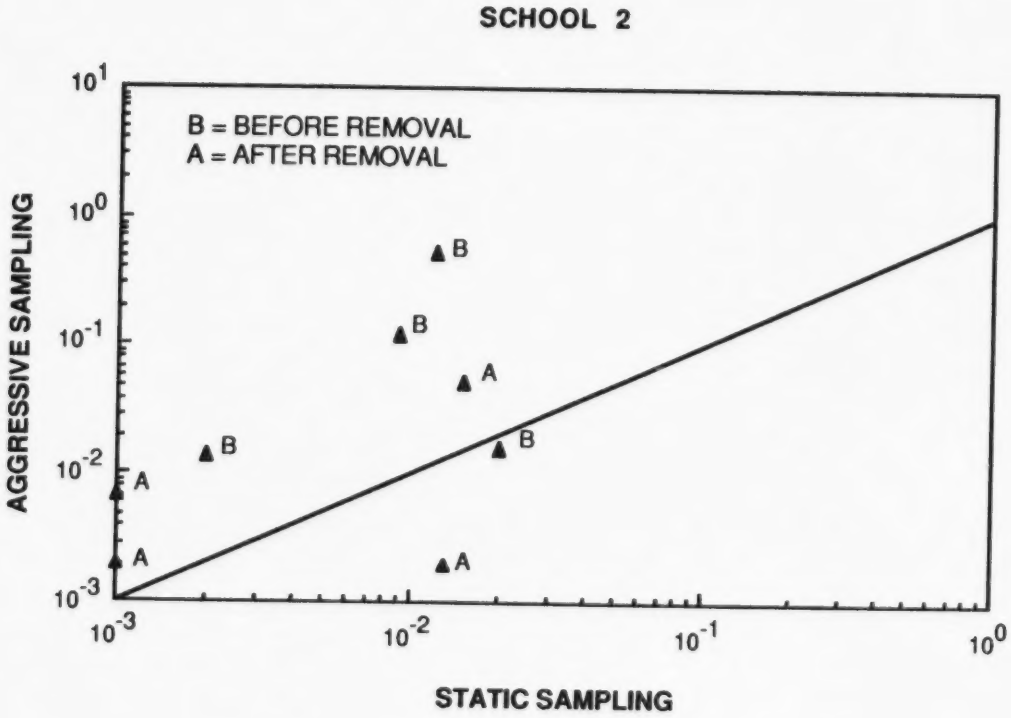

Figure 4. The relationship between average airbourne asbestos levels measured by static sampling and by aggressive sampling at school 2.

REFERENCES

1. U.S. Environmental Protection Agency. Guidance for Controlling Friable Asbestos-Containing Materials in Buildings. EPA 560/5-83-002. Office of Toxic Substances, Washington, D.C. 1983.

2. U.S. Environmental Protection Agency. Guidance for Controlling Asbestos-Containing Materials in Buildings. EPA 560/5-85-024. Office of Toxic Substances, Washington, D.C. 1985.

3. U.S. Environmental Protection Agency. Measuring Airborne Asbestos Following An Abatement Action. EPA 600/4-85-049. Environmental Monitoring Systems Laboratory, Research Triangle Park, N.C. and Office of Toxic Substances, Washington, D.C. November 1985.

4. U.S. Environmental Protection Agency. Asbestos-Containing Materials in Schools. Proposed Rule. Federal Register Vol. 52, April 30, 1987. p. 15820.

5. Carter, J. W., Baron, P. A., and Taylor, D. G. NIOSH 7402. NIOSH Manual of Analytical Methods. pp. 7402-1 to 7402-7. 1986.

6. Yamate, G., S. C. Agarwal, and R. D. Gibbons. Methodology for the Measurement of Airborne Asbestos by Electron Microscopy (Draft). Prepared by IIT Research Institute for the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. July 1984.

7. PEI Associates, Inc. Assessment of Assay Methods for Evaluating Asbestos Abatement Technology. Final Report prepared for U.S. Environmental Protection Agency, Contract No. 68-03-3197.

APPENDIX A

TEM CELLULOSE ESTER FILTER DATA LISTING

TABLE A-1. TEM CELLULOSE ESTER FILTER DATA LISTING

Sample ID		School	Period*	Type†	Site§	Struct./cm³**	No. of struct.
E-CE-M	164	1	1	2	7	0	0
EM	112	1	1	2	7	0	0
E-CE-M	196	1	1	2	7	0	0
EM	128	1	1	2	7	0	0
E-CE-M	192	1	1	2	7	0.007	1
E-CE-M	160	1	1	2	7	0	0
E-CE-M	156	1	1	0	6	0	0
E-CE-M	158	1	1	0	6	0	0
E-CE-M	154	1	1	0	6	0	0
E-CE-M	150	1	1	0	5	0	0
E-CE-M	152	1	1	0	5	0	0
E-CE-M	148	1	1	0	5	0	0
E-CE-M	146	1	1	0	4	0	0
E-CE-M	142	1	1	0	4	0	0
E-CE-M	144	1	1	0	4	0.006	1
EM	118	1	1	0	3	0	0
EM	120	1	1	0	3	0	0
EM	116	1	1	0	3	0	0
EM	110	1	1	0	2	0	0
EM	106	1	1	0	2	0	0
EM	108	1	1	0	2	0	0
EM	104	1	1	0	1	NA	NA
EM	100	1	1	0	1	0	0
EM	102	1	1	0	1	NA	NA
E-CE-M	206	1	1	1	6	0	0
E-CE-M	204	1	1	1	6	0.007	1
E-CE-M	208	1	1	1	6	0.007	1
E-CE-M	190	1	1	1	5	0	0
E-CE-M	188	1	1	1	5	0	0
E-CE-M	186	1	1	1	5	0.012	2
E-CE-M	170	1	1	1	4	0	0
E-CE-M	166	1	1	1	4	0.007	1
E-CE-M	168	1	1	1	4	0	0
E-CE-M	198	1	1	1	3	0	0
E-CE-M	202	1	1	1	3	0	0
E-CE-M	200	1	1	1	3	0	0
E-CE-M	176	1	1	1	2	0	0
E-CE-M	174	1	1	1	2	0	0
E-CE-M	172	1	1	1	2	0	0
E-CE-M	182	1	1	1	1	0	0
E-CE-M	180	1	1	1	1	0.003	0.5
E-CE-M	184	1	1	1	1	0	0
E-CE-M	194	1	1	1	0	NA	NA
E-CE-M	178	1	1	1	0	NA	NA

(continued)

TABLE A-1 (continued)

Sample ID		School	Period*	Type†	Site§	Struct. /cm³**	No. of struct.
EM	130	1	1	0	0	NA	0
E-CE-M	210	1	1	1	0	NA	NA
EM	114	1	1	0	0	NA	0
E-CE-M	162	1	1	0	0	NA	0
E-CE-M	1160	1	2	2	7	0.006	1
E-CE-M	1170	1	2	2	7	0	0
E-CE-M	761	1	2	2	7	0.007	1
E-CE-M	1000	1	2	2	7	0	0
E-CE-M	981	1	2	2	7	0.007	1
E-CE-M	719	1	2	2	7	0	0
E-CE-M	771	1	2	2	7	0	0
E-CE-M	701	1	2	2	7	0.0035	0.5
E-CE-M	1096	1	2	2	7	0	0
E-CE-M	1106	1	2	2	7	0	0
E-CE-M	1090	1	2	0	6	0.25	37
E-CE-M	1094	1	2	0	6	0.55	78
E-CE-M	1092	1	2	0	6	0.65	95
E-CE-M	979	1	2	0	5	0.073	10
E-CE-M	975	1	2	0	5	0.22	30
E-CE-M	977	1	2	0	5	0.13	18
E-CE-M	695	1	2	0	4	0.094	11
E-CE-M	699	1	2	0	4	0	0
E-CE-M	697	1	2	0	4	0.009	1
E-CE-M	1166	1	2	0	3	0.014	2
E-CE-M	1168	1	2	0	3	0.014	2
E-CE-M	1164	1	2	0	3	0.067	9.7
E-CE-M	759	1	2	0	2	0.82	99
E-CE-M	757	1	2	0	2	0.68	91
E-CE-M	755	1	2	0	2	0.45	56
E-CE-M	689	1	2	0	1	0.009	1
E-CE-M	693	1	2	0	1	0.023	3
E-CE-M	691	1	2	0	1	0.008	1
E-CE-M	1172	1	2	0	0	NA	0
E-CE-M	1098	1	2	0	0	NA	0
E-CE-M	763	1	2	0	0	NA	0
E-CE-M	983	1	2	0	0	NA	0
E-CE-M	1102	1	2	1	6	1.52	109
E-CE-M	1100	1	2	1	6	1.47	108
E-CE-M	1104	1	2	1	6	0.98	98
E-CE-M	992	1	2	1	5	0.05	7
E-CE-M	988	1	2	1	5	0.064	9
E-CE-M	990	1	2	1	5	0.042	6
E-CE-M	713	1	2	1	4	0	0

(continued)

TABLE A-1 (continued)

Sample ID	School	Period*	Type†	Site§	Struct. /cm³**	No. of struct.
E-CE-M 717	1	2	1	4	0.009	1
E-CE-M 715	1	2	1	4	0	0
E-CE-M 1158	1	2	1	3	0.038	6
E-CE-M 1154	1	2	1	3	0.071	11
E-CE-M 1156	1	2	1	3	0.099	16
E-CE-M 769	1	2	1	2	0.073	9
E-CE-M 765	1	2	1	2	0.038	5
E-CE-M 767	1	2	1	2	0.0685	9.5
E-CE-M 707	1	2	1	1	0.023	3
E-CE-M 709	1	2	1	1	0	0
E-CE-M 711	1	2	1	1	0	0
E-CE-M 721	1	2	1	0	NA	0
E-CE-M 723	1	2	1	0	NA	0
E-CE-M 1162	1	2	1	0	NA	0
E-CE-M 777	1	2	1	0	NA	0
E-CE-M 1002	1	2	1	0	NA	0
E-CE-M 1108	1	2	1	0	NA	0
E-HI-M 601	2	1	0	4	0.02	3
E-HI-M 599	2	1	0	4	0.01	2
E-HI-M 600	2	1	0	4	0.007	1
E-HI-M 597	2	1	0	3	0	0
E-HI-M 596	2	1	0	3	0	0
E-HI-M 595	2	1	0	3	0.007	1
E-HI-M 590	2	1	2	5	0	0
E-HI-M 598	2	1	2	5	0	0
E-HI-M 585	2	1	2	5	0	0
E-HI-M 603	2	1	2	5	0	0
E-HI-M 582	2	1	0	2	0	0
E-HI-M 583	2	1	0	2	0	0
E-HI-M 584	2	1	0	2	0.06	7
E-HI-M 581	2	1	0	1	0.02	3
E-HI-M 580	2	1	0	1	0	0
E-HI-M 579	2	1	0	1	0.008	1
E-HI-M 607	2	1	1	4	0.4	60
E-HI-M 609	2	1	1	4	0.93	91
E-HI-M 608	2	1	1	4	0.21	32
E-HI-M 605	2	1	1	3	0.04	6
E-HI-M 606	2	1	1	3	0.006	1
E-HI-M 604	2	1	1	3	0.01	2
E-HI-M 593	2	1	1	2	0.04	6
E-HI-M 591	2	1	1	2	0	0
E-HI-M 592	2	1	1	2	0.008	1
E-HI-M 589	2	1	1	1	0.12	15

(continued)

TABLE A-1 (continued)

Sample ID	School	Period*	Type†	Site§	Struct. /cm³**	No. of struct.
E-HI-M 587	2	1	1	1	0.15	20
E-HI-M 588	2	1	1	1	0.06	8
M 1301	2	2	0	4	0.03	4
M 1303	2	2	0	4	NA	NA
M 1302	2	2	0	4	0	0
M 1324	2	2	0	3	0	0
M 1323	2	2	0	3	0	0
M 1325	2	2	0	3	0	0
M 1326	2	2	2	5	0	0
M 1305	2	2	2	5	0	0
M 1331	2	2	2	5	0	0
M 1313	2	2	2	5	0	0
M 1322	2	2	2	5	0	0
M 1317	2	2	2	5	0	0
M 1298	2	2	0	2	0	0
M 1300	2	2	0	2	0.01	2
M 1299	2	2	0	2	0.03	4
M 1316	2	2	0	1	0	0
M 1315	2	2	0	1	0	0
M 1314	2	2	0	1	0	0
M 1310	2	2	1	4	0.07	9
M 1311	2	2	1	4	0.02	2
M 1309	2	2	1	4	0.07	9
M 1328	2	2	1	3	0.007	1
M 1330	2	2	1	3	0	0
M 1329	2	2	1	3	0	0
M 1306	2	2	1	2	0	0
M 1308	2	2	1	2	0.007	1
M 1307	2	2	1	2	0	0
M 1321	2	2	1	1	0.02	3
M 1320	2	2	1	1	0	0
M 1319	2	2	1	1	0	0

* Period:
1=before removal
2=after removal

† Type:

0=static indoors
1=aggressive indoors
2=static outdoors

§Site Index:

School 1 0=blank	School 2 0=blank 0=blank
1=2nd floor science lab	1=room 22
2=room A255	2=room 10
3=room A222	3=room 18A
4=home economics room	4=room 2
5=math resource center	5=roof
6=room 211S	
7=roof	

** NA = not available; missing values were replaced with 0 counts.

APPENDIX B

EXAMPLE Z-TEST CALCULATION

CALCULATION OF Z-TEST WORKSHEET

(Note: The number of inside samples does not meet the minimum AHERA requirement of 5.)

Inside Work Site ID No. School 1 Site 2

Outside Work Site ID No. School 1, Outdoor

n_i = number of inside samples = 3

n_o = number of outside samples = 10

	INSIDE SAMPLES (f/cc)	LOG INSIDE SAMPLES	OUTSIDE SAMPLES (f/cc)	LOG OUTSIDE SAMPLES
(1)	log (.072) =	-2.631	log (.006 / .007*) =	-5.116 / -4.962
(2)	log (.038) =	-3.270	log (.007 / .007*) =	-4.962 / -4.962
(3)	log (.073) =	-2.617	log (.007 / .007*) =	-4.962 / -4.962
(4)	log ( ) =		log (.007* / .0035) =	-4.962 / -5.655
(5)	log ( ) =		log (.007* / .007*) =	-4.962 / -4.962
	Total =	-8.519	Total =	-50.466
	$\bar{Y}_i$ = Total ÷ n_i =	-2.840	$\bar{Y}_o$ = Total ÷ n_o =	-5.047

(a) $\bar{Y}_i - \bar{Y}_o$ = 2.207

(b) $\frac{1}{n_i} + \frac{1}{n_o}$ = 1/3 + 1/10 , $\sqrt{\frac{1}{n_i} + \frac{1}{n_o}}$ = 0.658

(c) $0.8 \times \sqrt{\frac{1}{n_i} + \frac{1}{n_o}}$ = 0.527

$$z = \frac{\bar{Y}_i - \bar{Y}_o}{0.8\sqrt{\frac{1}{n_i} + \frac{1}{n_o}}} = \text{(a)} \div \text{(c)} = 4.19$$

Conclusion: X Work site fails if z > 1.65

_____ Work site passes if z < 1.65

*A measured value of 0 is replaced by the analytical sensitivity, 0.007 f/cc.

Source: Federal Register, Vol. 52, No. 83, Thursday, April 30, 1987, Proposed Rules, p. 15867.